NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

AN INVESTIGATION OF COMMUNICATIONS ARCHITECTURE IMPACT ON COMBAT EFFECTIVENESS USING THE NAVAL SIMULATION SYSTEM

by

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March 2008

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** March 2008	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: An Investigation of Communications Architecture Impact on Combat Effectiveness Using the Naval Simulation System	**5. FUNDING NUMBERS**
6. AUTHOR(S) Peter C. Hakewessell	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	**10. SPONSORING/MONITORING AGENCY REPORT NUMBER**

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT	**12b. DISTRIBUTION CODE**
Approved for public release; distribution is unlimited	A

13. ABSTRACT (maximum 200 words)

This research study evaluates the ability of the Naval Simulation System (NSS) to model how changes in communication architecture for a given scenario contribute to combat effectiveness. The scenario used for this study models communication capability associated with the Marine Corps Warfighting Lab, Sea Viking 06 distributed operations scenario using the NSS. In addition, an evaluation of alternative system configurations in the communication structure is obtained in order to determine how bandwidth constraints on specific systems limit mission effectiveness. The NSS is a multi-warfare mission area tool designed to support operational commanders in developing and analyzing operational courses of action at the group/force level. Recent evolutionary changes now provide the NSS the ability to perform communication analysis of routed and circuit switched systems in addition to course of action analysis of modifiable assets in a programmed scenario. This capability makes the NSS unique among modeling and simulation tools.

The simulation model experiment contains seven communication architectures with progressively reduced bandwidth capacity. Each architecture excursion has the same scenario timeline and measurement parameters. The results of each excursion are graphically compared and statistically analyzed to identify communication performance impacts at critical events throughout the scenario. A correlation is made with communication performance and combat effectiveness when the enemy force attrition is compared over each excursion to identify if a decrease in combat effectiveness can be seen as a result of reduced communication capability. The results show that the NSS can be used appropriately and accurately to represent communication system effectiveness within a distributed operation scenario supported by the ESG.

The objective of this study directly supports the Network Centric Operations (NCO) framework at the information domain by demonstrating the ability of the NSS to measure quality of a communication plan and its value within a command and control system architecture as applied to force effectiveness.

14. SUBJECT TERMS Expeditionary Strike Group, Distributed Operations, Naval Simulation System, C4I System Modeling, Communication Systems Modeling, Expeditionary Tactical Communication System, ETCS, ESG, NSS	**15. NUMBER OF PAGES** 75
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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AN INVESTIGATION OF COMMUNICATIONS ARCHITECTURE IMPACT ON COMBAT EFFECTIVENESS USING THE NAVAL SIMULATION SYSTEM

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY
COMMAND, CONTROL, COMMUNICATIONS (C3)

from the

NAVAL POSTGRADUATE SCHOOL
March 2008

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ACKNOWLEDGMENTS

I would like to thank those who helped me through one of the most tedious and rewarding academic achievements I have had. I am grateful to Alex Callahan from the Naval Postgraduate School (NPS) for his patient advisement, laboratory support and encouragement in helping to forge this thesis to promote the capabilities of the NSS. I am indebted to James Johnson and George Berg from Northrop Grumman Integrated Systems Sector for sharing their vision of how NSS can be used in a combined acquisition and operational environment. I also would like to thank John Ruck from Roland and Associates (R&A) Corporation for sharing his detailed knowledge of the Naval Simulation System (NSS). Lastly, I would like to thank Jon and Julie for their hospitality, motivation and operational advice while constructing the experiment and drafting this thesis.

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I. INTRODUCTION

A. BACKGROUND

The movement toward network-centric operations (NCO) by the U.S. Armed forces has increased the need for communication systems that support emerging warfare concepts. In NCO, networked Joint Forces increase operational effectiveness by facilitating a dispersed force to move effectively, communicate, share common operational pictures and achieve the desired end state with minimal losses [OFT05]. The Navy and Marine Corps team have developed the FORCEnet operational construct and architectural framework as their path toward NCO. FORCEnet will guide the integration of sensors, networks, command and control, platforms and weapons into a networked, distributed combat force that is able to change based on the operational environment. It is the naval command and control (C2) component for Sea Power 21 and Expeditionary Warfare [NNWC06]. The Navy and Marine Corps have committed to FORCEnet as the architectural framework of the future, and are evolving their communications architectures in that direction.

To further articulate the FORCEnet vision, a capabilities document, commissioned by Naval Network Warfare Command and signed off by the Chief of Naval Operations and the Commandant of the Marine Corps, outlines a functional concept to establish a common direction for development of desired FORCEnet capabilities. Two of the 15 required capabilities describe a need for automated decision aids to simulate outcomes of possible courses of action and to rapidly incorporate new technology without disrupting the system [NNWC06]. To support these capabilities, a complete modeling and simulation (M&S) environment is required, both to provide course of action analysis and to provide technology integration testing to demonstrate warfare effectiveness in the network centric environment.

No single M&S solution exists that can support both warfare commanders and acquisition community decision making through incorporation of current communication technologies for the evaluation of both course of action and communication system alternatives with respect to combat power. Highly capable decision aids and analysis

tools are available that evaluate combat effectiveness and communication system performance separately. Common combat models such as THUNDER, JWARS and the early versions Naval Simulation System (NSS) proved useful as course of action analysis tools but lacked the ability to model communication system impacts. NETWARS, currently under development by SPAWAR, demonstrates military communication system performance, but lacks the ability to assess impacts to warfare effectiveness [Alspaugh04]. Newer versions of these tools have incorporated higher level architectures that allow federation between models.

The NSS is an object-oriented, Monte Carlo modeling and simulation tool under development by SPAWAR and Metron, Inc. for CNO N6M. NSS is a multi-warfare mission area tool designed to support operational commanders in developing and analyzing operational courses of action at the group/force level. Its initial attempt to simulate robust C4I entities and organizations makes it unique among M&S tools. In addition to course of action analysis, recent evolutionary changes to the NSS communication modeling algorithm provide the ability to perform in-depth analysis of routed and circuit switched communication systems in a programmed scenario. This thesis exercises these features using an Expeditionary Strike Group (ESG) scenario. This scenario provides an operationally relevant and unique opportunity to study communication system effects on combat effectiveness.

In addition to an interest in modeling communication systems in the NSS, the author is bound for an amphibious flagship, and wants to advance his knowledge in the communication architectures and challenges in the littoral combat environment. Also, these ships are currently deploying as ESG flagships, so he desires to expand knowledge to include ESG operations and related challenges. These factors motivated an experimental design that exercised the routed communications capability of NSS to assess possible communications architectures for ESG operations.

B. PROBLEM

This research first examines the utility of the NSS for modeling communications systems with the new routed communication module. To assess the utility of the NSS, simulated components of an ESG with associated communication systems were crafted in the NSS, and then tested in scenario excursions. These tests were then used to determine

whether the NSS environment and the measures of effectiveness (MOEs) available within the NSS database would be sensitive enough to support comparison of communication system alternatives. Having met these objectives, the capstone of this research was to utilize the combat model aspects of the NSS, combined with attrition type MOEs in the NSS, to connect communication architecture performance to overall combat effectiveness. Specifically, the thesis addresses the following three questions:

1. With the new routed communications feature for modeling communication systems, is the NSS the right tool for course of action analysis in a net-centric environment?

2. Does the NSS have the ability to generate data that will reflect changes in communication system performance due to changes in the communications architecture?

3. Does the NSS have the ability to reflect the impact of communication system performance on force effectiveness?

To address these questions, we will conduct an evaluation with NSS using different communication configurations, focusing first on a careful analysis of the simulated combat effectiveness observed across different communication architectures. We will then examine these combat effectiveness results for correlating data within communication performance data to further illuminate any differences. Our assessment of the utility of NSS will be based on a subjective evaluation of our experimental design, execution and analysis.

C. CHAPTER OVERVIEW

The remainder of this thesis is organized as follows:

Chapter II History, presents the historical evolution of NSS and its past use. In addition, we introduce alternate modeling solutions for comparison.

Chapter III Architecture & Analysis Method, explains the tactical scenario applied in the model and the NSS model development procedure, including details of the communication model parameters. The Distributed Operations concept and model analysis measures are presented, to include a description of lessons learned while building the model. Also, a description of the changes applied to the communication model and the specific analysis measures used to evaluate the model are given.

Chapter IV Results, describes the analysis strategy and provides a graphical and statistical presentation of the results.

Chapter V Conclusions and Recommendations, provides conclusions from the analysis and gives recommendations for future work.

Appendix A, details the Distributed Operations scenario and timeline.

Appendix B, lists the comprehensive communication MOEs available to evaluate the NSS model.

Appendix C, shows the connectivity diagram of the communication circuits modeled.

II. HISTORY

A. INTRODUCTION

Possible communication system modeling and simulation environments are presented in this chapter, to include a history of the NSS program.

B. THE NAVAL SIMULATION SYSTEM

1. Overview

The Naval Simulation System (NSS) is an object-oriented Monte Carlo modeling and simulation tool that provides a comprehensive multi-force modeling and simulation capability [Stevens00]. The NSS models surface, subsurface, air, ground, and space assets with their associated weapons, sensors, and C4I systems in coordination with user specified warfare commander's orders. The NSS is capable of representing C4I, logistics, force engagements and commander's tactics simultaneously throughout the multi-warfare simulation. The NSS currently supports a number of Naval theater operations such as: Naval and Joint operation planning and decision support, C4I analysis and assessment, Fleet exercises and experiments, and Fleet training. The software is written mostly in C++ and runs over networked computers in a client-server or stand alone configuration under Microsoft Windows operating system. The NSS version used for this experiment is v.3.3.3 build 14.

The NSS models the interaction of various force assets, based on initial plans and the dynamic reaction of commanders. Dynamic command decisions in the NSS are based upon a generated, perceived tactical picture, not the ground truth position of targets. The tactical picture is generated from the inputs of customizable organic and remote sensors. Warfare Commanders dynamically respond to this perceived tactical picture based on tactics tables and the availability of resources [Stevens03].

To facilitate scenario development, the NSS Graphical User Interface (GUI) provides a five step scenario creation process. Force alliances, command structures and associated assets are assigned to warfare commanders. Initial command and control plans and response tactics are defined for each commander. Motion plans, communication networks, sensor schedules and any logistics plans are defined. Mission

plans for surveillance and reconnaissance assets and strike aircraft are defined. Finally, over 100 predefined and user modifiable analysis measures can be generated. A fully defined, classified and unclassified, modifiable baseline asset database is included with the proprietary commercial off-the-shelf NSS data dictionary.

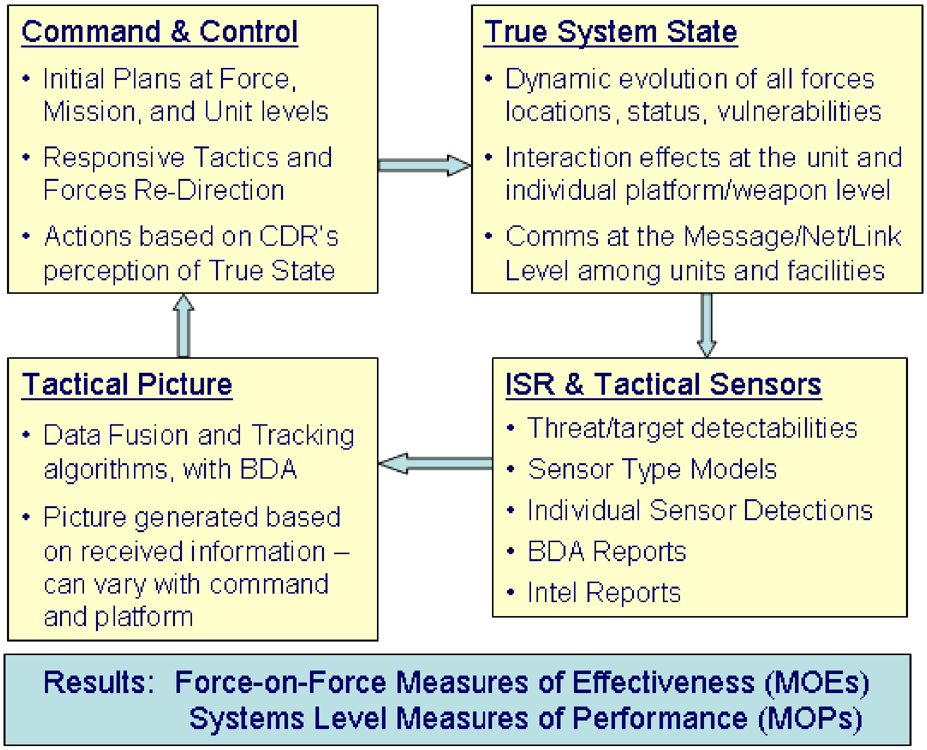

Figure 1. NSS Functional Segments (From [Stevens03])

For analysis, the NSS is capable of generating data on a variety of pre-programmed and user definable performance measures. The output spreadsheets provide individual and replication averaged, time based MOE values for post processing analysis and graphical display through an export utility directly to Microsoft Excel.

2. History

In 1995, under Defense Advanced Research Projects Agency (DARPA) guidance, each of the military branches initiated efforts to exploit emerging technologies in object oriented software development and computing power to develop higher resolution simulation systems. The goal was to achieve faster, more detailed analysis and training avenues for regional commanders on current war plans.

DARPA entered into a large effort to produce a Synthetic Theater of War (STOW) capability using high-speed computing to achieve sufficiently detailed representations of key warfighting platforms to provide realistic training for Joint Forces [Hout03]. In 1995 the DoD Modeling and Simulation Office (DMSO) initiated a major simulation system interoperability effort. An Architecture Management Group (AMG) was formed to define and prototype a new architecture to provide a general means of achieving interoperability between different simulation system software [Hout03]. The High Level Architecture (HLA) standard was developed to fulfill this initiative of model interoperability. The NSS became a major part of the DMSO Architecture Management Group initiative as the Navy's representative system, along with other Service's training and analysis modeling software systems.

During 1995, Space & Naval Warfare (SPAWAR) Systems Command PMW-153 and Metron Inc. jointly developed NSS for Chief of Naval Operations, C2 Systems Division and established the NSS Program Office. Throughout the development phase, the NSS was employed in numerous operational fleet exercises and Fleet Battle Experiments (FBE). With its emphasis on C2 evaluation, the NSS was first tapped to support the FBE series in the role of scenario stimulator for C2 systems. NSS was modified to generate OTHT-Gold contact reports that were fed to C2 systems being evaluated in FBE-B. A single replication of the Monte Carlo NSS simulation was run in real-time mode and the tactical picture simulated for human operators manning the C2 system [Gagnon/Stevens99]. By 1998 the NSS was certified Global Command Control System (GCCS) compliant, demonstrating its potential interoperability with operational C4I systems. The NSS has also proven to be a valuable warfare assessment tool. Fulfilling a task for the Commander, Pacific Fleet in 1998, the NSS used a Korean Peninsula scenario for preliminary assessment of the potential warfare benefits of the Navy's IT-21 initiative. The result of that study was that distributed command would result in major timeline improvements in a counter-SOF mission for that theater [Atamian99].

In 2002 program sponsorship shifted from the C2 System Division to the Navy Modeling and Simulation Management Office (NAVMSMO). In January 2003, the program executive for NSS was shifted from SPAWAR to NPS. In October 2003,

NAVMSMO transferred management of the NSS program to Naval Air Systems Command (NAVAIR) Research and Engineering Group, Warfare Analysis Center. This move placed the NSS into an acquisition and management organization, with NPS as the independent Verification and Validation Agent (V&VA). The NSS user community, consisting of leading defense contractors and naval systems commands, used the assessment tool to evaluate the Multimission Maritime Aircraft Project, Coast Guard Deepwater Project, DD-X, Littoral Combat Ship and UAV development studies. The following initiatives are recent NSS projects that the Naval Postgraduate School has participated in:

- N81 Net Assessment – Net Assessment of the Navy's current and future warfighting capabilities. The capabilities based assessment looked at previous warfighting capabilities analyzed against new focused programs in all warfare areas. The Information Dominance assessment team assessed the optimal mix of networked Intelligence Surveillance and Reconnaissance (ISR) assets and sensors that would increase a warfare commander's situational awareness [Levitt04]. The net assessment used two modeling programs NSPAT and NSS to determine ISR sensor mix and the impact on simulated campaign outcome. The use of NSS provided a comprehensive assessment to analyze all warfare areas on the campaign level including explicit C4I capabilities. Results of the NSS analysis revealed bottlenecks in communication paths, network nodes and limits in data collection capabilities that may exceed current Naval asset capacity [Levitt04].
- World Class Modeling Initiative – The Naval Postgraduate School (NPS) MOVES Institute developed this initiative, sponsored by OPNAV N81. It successfully fulfilled the Office of the Secretary of Defense's (OSD) Analytical Agenda to transform the way the DoD applies Modeling and Simulation (M&S) to the challenges of today's warfighters [MOVES04]. To support this initiative, required M&S capabilities were developed that allow the move away from monolithic, closed system designs, to open M&S frameworks that permit modular, loosely coupled components to be rapidly integrated to create agile analytical capabilities to address a variety of missions conducted in asymmetric warfare [MOVES04]. Recent advances in the Extensible Modeling and Simulation Framework (XMSF) program allow the exploitation of Internet technologies and the ability to meet the DoD M&S requirements that deal with analysis, training, acquisition, and experimentation. Internet technologies, including Extensible Markup Language (XML) based languages and service oriented architectures, will enable a new generation of distributed M&S applications to be developed.

Objectives of the World Class Modeling Initiative are to [MOVES04]:

- Develop a framework and proof of principle demonstration of the use of Web based technologies to interface the NSS and Combined Arms Analysis Tool for the 21st Century (COMBATXXI) via Web services and the NPS SimKit API.
- Develop a visual user interface for creation of event graph representations of discrete event simulation components.
- Design and conduct demonstrations of the analysis capabilities of the hybrid NSS/COMBATXXI environment.
- Enhance the NPS Anti-Terrorism/Force Protection planning tool.

C. NETWARS

The Network Warfare Simulation (NETWARS) is a modeling and simulation tool that assists military planners to construct a computer representation of a communication network structure. It is under development by the Joint Chiefs of Staff and the Defense Information Systems Agency (DISA). The Space and Naval Warfare Systems Center San Diego (SSC SD) is the Navy representative for NETWARS related efforts, which include Architecture and Standards, Working Integrated Product Team (WIPT) contributions, model development and assessments [Alspaugh04]

The NETWARS computer model is applied to a geographical or relational map and used to simulate the operational dynamics of message flow through the simulated strategic, operational, and tactical military voice and data network structures. The model inputs are based on user inputted traffic density. Simulation model communication behavior can be provided down to the packet and protocol level. NETWARS analyzes the results of a simulation session and produces a set of Measures of Performance (MOP) in graphical form. The measures allow configuration decisions that effect resource and bandwidth management that can be applied to communication plans drafted as part of the Joint Planning Process [Opnet04].

Although NETWARS has proved a capable tool for communication systems modeling, for this study NSS was the better choice to meet our objectives. NETWARS is currently unable to directly evaluate command and control systems effectiveness in terms of a warfare commander's force effectiveness. Further, NETWARS simulates message

capacity by predefined Information Exchange Requirements (IER). These parameters specify message traffic capacity over time; thus, NETWARS can be used to identify network design deficiencies by exercising the simulated communication system at the upper-limit or worst case. Within NSS, the message traffic varies based on the way the simulated combat scenario unfolds. This event-triggered message generation within NSS provides the crucial link connecting communications system performance to combat power.

D. SUMMARY

Previous studies with the NSS conclude that the modeling tool is well suited for detailed campaign level warfare assessments. This study incorporates the routed communication feature to assess C4I system modeling impact analysis on combat effectiveness. With a valid scenario, command and control organization, communication plan and experiment metrics, a simulation model will give acceptable results to analyze. The building blocks and experiment design of the simulation model for analysis of communication alternative impacts will be discussed in Chapter III.

III. ARCHITECTURE & ANALYSIS METHOD

A. INTRODUCTION

This chapter describes the process used to build and analyze the simulation model in the NSS. First, a tactical scenario is selected based on the warfare area being studied. Second, a command and control structure is determined for tactical decisions, which then drives the design of the communication structure, which is articulated in a communication plan. Next, measures of effectiveness (MOE) are selected which will determine the attributes or characteristics of interest to the analysis. Finally, the model is programmed based on the scenario events, communication plan and selected measures of effectiveness.

B. OVERVIEW

1. Approach

The methods chosen to answer the three thesis questions are briefly described below in reverse order for ease of understanding. It was decided to answer the third question (assessing the NSS ability to reflect the impact of communication system performance on force effectiveness) objectively, based on one or more measures of force effectiveness (MOFE). The second question (assessing the NSS ability to generate data that will reflect changes in communication system performance due to changes in the communications architecture) would be answered by visually comparing graphical presentation of time traces of selected communication system measures of effectiveness (MOE) across the scenario, and if differences in force effectiveness were detected (question three above), the time traces would be examined to see if they could be used as diagnostic aids to determine if the communication system impacted force effectiveness. Finally, the first question (assessing the usability of NSS for course of action analysis in a net-centric environment, with the new routed communications feature for modeling communication systems) would be answered subjectively, based on the author's experience during the model development and analysis effort.

Prior experiments using the NSS as an analysis tool provided insight into the capabilities of the modeling program. Examining the scenario requirements for these analyses and reviewing the NSS documentation provided insights into the command and control elements to needed to create realistic communication architectures that included current technology. These previous studies also revealed measurement avenues that could be applied to communication system architectures, we also examined alternative modeling tools, such as NETWARS.

The Modular Command and Control Evaluation Structure (MCES) was used as a guide to develop an analysis structure to examine the NSS model's ability to produce useful results about the effectiveness of basic C4I system alternatives. Quantitative and qualitative C4I measures of effectiveness (MOEs) developed thorough the Modular Command and Control Evaluation Structure (MCES) were broken down into specific physical parameters that were then programmed into the NSS.

Once the overall experimental construct was established, (a single tactical scenario and several communications architectures – see Scenario Selection below) the next steps were to select the tactical scenario and then develop several alternate communications architectures that, coupled with the scenario would provide data to answer the thesis questions. It was decided to construct variants of the communication architecture that progressively constrain the bandwidth of selected networks, and therefore were expected to impact both communication system performance and warfighting effectiveness.

To obtain communication system performance data, several NSS communication system MOEs were identified, modified and assigned to gather data from the communication model to determine if they adequately reflect the communication system changes. One NSS attrition MOE was also selected to determine if changes in communication architecture led to changes in warfighting effectiveness.

Seven communication plans (a baseline and six alternatives with progressively reduced bandwidth) were each combined with the fixed tactical scenario and then programmed as separate excursions of the model. The model was then executed seven times for each excursion and values of the communication system and attrition MOEs

were collected for each run. The attrition MOE values were compared statistically to test differences on force effectiveness and time traces of the communication system MOEs were graphically compared, both to visualize any effect of reduced bandwidth on communication system effectiveness and to assess whether observable changes in communication performance clearly correlated with changes in combat performance. Finally, the author's experience in preparing for and conducting the analysis was used to assess usability of the NSS.

C. SCENARIO SELECTION

To keep the study simple yet effective, the initial concept for scenario design was to take a three-tiered approach to model development. The first tier would be a limited objective, time and force scenario implementing Special Operations Forces (SOF) from amphibious platforms, in a maritime environment, executing intelligence gathering and destruction of a static threat. The second tier would involve more maritime forces in a littoral environment executing a Maritime Interdiction Operation (MIO) of a local fishing vessel. The last tier would build on the prior two scenarios, using a single communication architecture. This larger scale scenario would entail a Non-combat Evacuation Operation (NEO) of civilians from a port city. This military operation would involve a larger force complement such as a Marine Expeditionary Unit (MEU) to include air support and more specialized infantry platoons. The experiment would have focused on analysis of the impact on force effectiveness of an anticipated increase in communication load due to increased force size and mix and increased operational complexity.

It became evident that the tiered scenario concept would not fully support the stated goals of the thesis for several reasons. Most important, it lacked the experimental control needed to properly examine the effect of alternate communications architectures on force effectiveness. It was then decided that a single expeditionary warfare scenario, coupled with changes in the communication architecture, would better accomplish the experimental objectives. Specifically, this would enable a study of changes in force effectiveness due to alternate communication architectures.

At this point, research into the specifics of an appropriate was undertaken. To reduce the time required to program the scenario into the NSS, and to provide credibility,

it was hoped that a previously employed NSS model could be located that involved or could be converted to involve expeditionary warfare, and could also be programmed to utilize the new routed communication feature. With these goals in mind, a search was conducted of existing NSS scenarios. No existing NSS scenario that met these requirements was uncovered, so the author began looking for non-NSS scenarios that could be modeled in NSS to meet the requirements.

This led to the scenario that the Marine Corps Warfighting Laboratory developed for the Distributed Operations Seminar Wargame conducted in 2004 in preparation for the Sea Viking 06 Warfighting Experiment. This scenario deploys a Distributed Operations (DO) Platoon to conduct reconnaissance of suspect terrorist activity, using remote sensors and direct infiltration, in preparation for possible air strikes. The DO Platoon is supported by an amphibious ready group (ARG) as part of an ESG deployment to assist in the security needs of an allied coastal nation. The decision was made to develop several NSS models of the DO mission, each incorporating routed communications architectures of progressively decreasing bandwidth.

D. TACTICAL SCENARIO DESIGN

1. Background

Through the Sea Viking 2006 experimental campaign plan, the Marine Corps Warfighting Laboratory (MCWL) is tasked to develop requirements to support the additive capability of a Distributed Operations (DO) capable platoon. Toward that goal, a scenario based on the evolving Distributed Operations concept was developed and used in DO Seminar Wargame number one, conducted in November 2004 [MCWL04]. The tactical scenario developed for the thesis is based on the MCWL DO scenario, and was developed with assistance from MCWL.

2. Distributed Operations

The Commandant of the Marine Corps charged the Marine Corps Combat Development Command to explore transformation options that are in-line with future force employment requirements. The requirements rise from the need to counter a different type of globally distributed adversary, one who is ruthless, unpredictable, and adaptive. On the premise that Expeditionary Strike Groups (ESGs) employ Marine forces, a collaborative experimentation effort between one rifle platoon from a selected

Marine Expeditionary Unit (Special Operations Capable) and the Marine Corps Warfighting Laboratory (MCWL) is underway to craft tactics, techniques and procedures (TTPs) through the Sea Viking Experimentation Program. The next iteration of the Sea Viking Experiment will entail live-force experimentation with Distributed Operations (DO) as its key component. This concept-based experiment is fulfilled by Sea Viking 06.

The intent of DO is to provide a relevant, additional capability that capitalizes on new tactics, techniques, and procedures (TTP) and leverages advanced technologies, particularly those that are communications related [Wilson04].

The DO concept works to leverage improvements achieved through FORCEnet. DO describes an evolving concept that seeks to maximize the Marine Air Ground Task Force (MAGTF) commander's ability to employ tactical units across the depth and breadth of a nonlinear battlespace, in order to achieve favorable intelligence-driven engagements as part of the Joint Force Commander's overall campaign [Goulding05].

The DO concept, as defined by MCWL, envisions a specially trained and equipped rifle platoon from the ground combat element (GCE) of a Marine Expeditionary Unit (MEU). This enhanced platoon provides the Marine Expeditionary Unit Special Operations Capable (MEU(SOC)) commander, a specialized capability to locate, close with and destroy the enemy through enhanced day/night observation equipment, patrolling skills, vehicle mobility, improved rifleman communication suite, crew-served weapons, and an ability to provide terminal guidance for joint fires [Wilson04]. The notional platoon is built around three 13-man squads with enhanced equipment and a 5-man command element consisting of a platoon leader, platoon sergeant, guide, radio operator and corpsman.

Wargames conducted to provide direction to MCWL in the development of the DO concept have identified critical capabilities of the DO platoon that differ from current rifle platoon capabilities. Some findings are that DO squads must be able to collect, transmit and receive actionable intelligence. This capability will require additional training in surveillance and reconnaissance patrolling and procedures for logistical support requirements [Wilson04]. Other conclusions of particular interest are the need for the DO unit to provide positive identification and likely intent of enemy units. This

capability is of particular importance when implementing rules of engagement in support of Global War on Terrorism. The Marine Corps hopes to find solutions to these critical capability shortfalls through future concept development, technology innovation and experimentation.

E. DO COMMAND AND CONTROL STRUCTURE

In this study the command and control (C2) operational structure is based on the ESG structure used in west coast deployments where the Amphibious Squadron (PHIBRON) Commodore acting as Amphibious Warfare Commander and Marine Expeditionary Unit (MEU) Commander acting as Expeditionary Warfare and Landing Force Commander share a supporting-supported relationship. The supported Commander gives direction, but does not specify particular assets to achieve the desired end state. Figure 4 shows the Navy ESG Commander and Marine Deputy Commander having a joint role as Strike Warfare Commander. As an added capability to the Rifle Company in the Ground Combat Element, a Distributed Operations mission commander would provide contact and situation reports on designated MEU voice or data communication circuits to the Ground Combat Element Commander directing the mission from a Supporting Arms Coordination Center (SACC) onboard the MEU command ship, which is represented by the LHA in this scenario. In a typical ESG, the Landing Force Operations Center (LFOC) is the C4I coordination hub, consolidating reports from the SACC and requesting support from the Tactical Air Coordination Center.

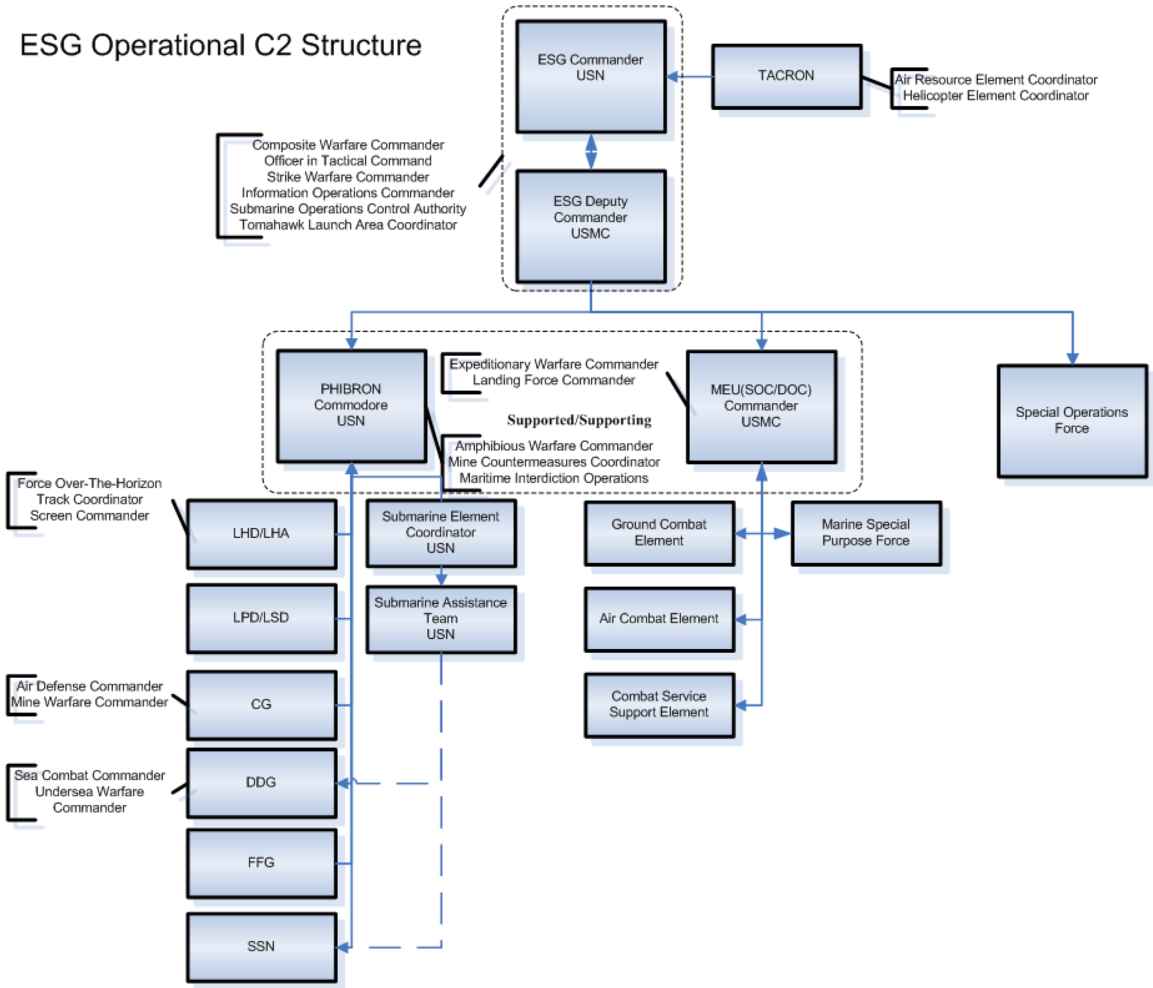

Figure 2. ESG Operational C2 Structure (After [Hutchins05])

F. TACTICAL SCENARIO

The storyboard and scenario details are included in Appendix A. They were used as an object movement timeline reference and a communication load and delay analysis reference to significant events in the scenario.

G. COMMUNICATION SYSTEM MODEL DESIGN

An ESG communication system plan was drafted that incorporated the communication systems in use throughout the scenario. The communication architecture model in this study (Appendix D) follows the command and control structure in Figure 2. Communication nodes are designated at the appropriate warfare commander asset with circuits in a typical ESG communication plan, connecting all scenario assets. The Strike Warfare Commander on the LHA receives contact reports and track updates from all

assets, and has the ability to issue tactical orders to the DO Platoon Commander and air assets through multiple terrestrial and satellite communication networks. The DO Platoon Commander, deployed with the DO platoon, receives and relays contact and track reports from the supporting squads and unmanned sensors and issues movement orders to the squads through line of sight communications.

1. Communication System Description

a. Introduction

The primary communication devices used in the scenario are described in the following paragraphs. These systems are used to provide decision support and command and control avenues to the MEU Commander. Friendly and enemy force location data is entered into the tactical systems and passed to other display and processing systems by the data links described below.

b. Iridium Network

Iridium satellite service provides global voice and data connectivity through the use of a 66-satellite low earth orbit constellation. Commercial customers connect to other Iridium satellite telephones using the cross-linked network and to the Public Switched Telephone Network (PSTN) through a gateway located in Tempe, AZ. Government customers use the dedicated Enhanced Mobile Satellite Services (EMSS) to connect in a similar manner to the Defense Information Services Network (DISN) through a similar gateway in Hawaii providing secure capable service to the Defense Switch Network (DSN), the commercial and international long-distance network, the NIPRNET and the SIPRNET. The EMSS gateway provides 2.4 kilobits to 9.6 kilobits per second voice and data connectivity and supports NSA Type-1 encryption when required. [Ellen03]. EMSS service is offered through the Defense Information System Agency to DoD, other Federal departments and agencies, state and local governments, and Joint Staff approved foreign and allied government users. [DISA05].

c. Expeditionary Tactical Communications System (ETCS)

ETCS is a prototype netted radio system that uses the Enhanced Mobile Satellite Service (EMSS) on the commercial Iridium constellation. The system requirements are to provide on the move (OTM) and over the horizon (OTH) communication capability from seabased command and control centers to dismounted

tactical maneuver units operating in complex terrain ashore with a minimum ground infrastructure. The system has the capability to transmit voice and data messages and is integrated with current Marine Corps C2 systems such as the Command and Control Personal Computer (C2PC) application running on the Data Automated Communication Terminal (DACT) and Commander’s Digital Assistant devices. The effectiveness of ETCS as a viable tactical communication backbone circuit was evaluated during MCWL Sea Viking 06 Advanced Warfighting Experiment [MCWL05].

General Dynamics C4 Systems is developing the networked radio system that enables users to share a single channel for voice and data communication in a talk group or one-to-many(broadcast) configuration. This system is more efficient than the traditional cellular one-to-one configuration, and uses a push to talk connection with a short setup time. This automatic multiple access configuration forces users to an idle channel pool so others have access to the same network enabling bandwidth management [Paldan04].

The use of EMSS voice and data communication meets USMC over-the-horizon and on-the-move operational requirements of tactical units in Expeditionary Maneuver Warfare [Paldan04]. Iridium equipment configured to use talk groups can connect distributed, inter-theater assets and extend these assets to wired government network users through the DoD EMSS gateway. The Marine Corps and General Dynamics tested this enhanced capability in the ETCS configuration shown in Figure 1 to include data nets, position location information (PLI) and blue force tracking (BFT) during the MCWL Sea Viking 06 Experiment [Paldan04].

Figure 3. ETCS Sea Viking 2006 Configuration (From [GeneralDynamics04])

d. Link 11/16 Tactical Data Links

Tactical Digital Information Link (TADIL) A/B [Link-11] employs data network communication techniques and a standard message format to exchange digital information among airborne [TADIL-A] as well as land-based and shipboard [TADIL-B] tactical data systems. Link 11 provides high speed computer-to-computer digital radio communications in the high frequency (HF) and ultra-high frequency (UHF) bands among Tactical Data System (TDS) equipped ships, aircraft and shore sites [GlobalSecurity.org05]. Link 16 is the primary real-time tactical data link for the

exchange of TADIL-J messages. It is used to support C2, navigation and identification for tactical military operations providing secure, jam-resistant digital communications over UHF bands. These data links provide the raw data to combat systems such as the Joint Tactical Information Distribution System (JTIDS) and Advanced Combat Direction System (ACDS). This data is distributed to GCCS-M where it provides a global operating picture to the warfighter.

e. Global Command Control System Maritime (GCCS-M)

Global Command Control System Maritime (GCCS-M) is the naval variant of GCCS; it was formerly the Joint Maritime Command Information System (JMCIS). The system establishes and presents a fused, real-time common operational picture of the battlespace to the warfighter for all automated C2 functions used for situational awareness and decision making. These C2 functions include: track management sharing between Advanced Combat Direction System (ACDS); Command and Control Personal Computer (C2PC); and Theater Battle Management and Core System (TBMCS); imagery and video management and sharing between Joint Service Imagery Processing System (JSIPS), Image Product Library (IPL) and Unmanned Aerial Vehicle (UAV) data, targeting processes between Advanced Field Artillery Tactical Data System (AFATDS), Automated Deep Operations Coordination System (ADOCS). It provides a single, integrated, scalable C2 system to receive, correlate, fuse, and maintain geo-located track information on friendly, enemy, and neutral forces and integrates that information with intelligence and environmental information. GCCS-M also provides the joint operational planning and execution capabilities to plan, deploy, employ, and sustain armed forces. The system provides warfare commanders a single integrated workstation for generating, receiving and sharing secure C2 information. GCCS-M has been installed on all amphibious warships [NADPGR02].

2. Distributed Operations Communication Plan

The scenario requires point to point and multipoint communication paths between programmed assets in the model. The two DO Squads are aware of sensor data by line of sight radio circuits. This sensor data, as well as own asset location information is relayed through the platoon commander to the warfare commander on the LHA. The platoon commander passes this data using the ETCS terminal over the Iridium network. He also

receives orders from the warfare commander through a satellite communication (SATCOM) circuit. Both of these communication paths have secondary SATCOM and over-the-horizon HF circuits programmed for redundancy. The platoon commander passes these orders to the Squads for execution through line-of-sight UHF voice circuits. All data is fused with Link 11 and 16 data from organic aircraft and ESG sensors reporting own assets and each other throughout the scenario. All track data is presented to the warfare commander on a common picture by GCCS-M.

a. Researched Architecture

A baseline communication structure was formed from research into shipboard communication networks and C4I systems unique to a typical ESG. It was collected from multiple sources including Standing Naval Communication plans located in Naval Tactical Publication-4, Naval Warfare Publication-4. Typical bandwidth allocation for each circuit was obtained from research into each specific network and was helpful to determine communication node characteristics for each voice and data circuit.

Circuits selected to model in the NSS represent those necessary for mission accomplishment. Redundant secondary circuits were created for designated forces to use in the scenario. Appendix D shows a Communication Node Connectivity Description of the communication architecture modeled in this simulation.

H. NSS MODEL ARCHITECTURE DESIGN

1. NSS Object Database

The NSS unclassified Object Store is used to create the scenario specific Instance Archive database of default object templates that are used in the scenario. User defined objects are created from the object templates and individual object characteristics are defined based on scenario needs. Object characteristics include attached sensors, vulnerabilities, movement speed and attached communication terminals and nodes. The list of all objects available for use in the scenario is stored in the Instance Library shown in Figure 4, below. Communication nodes, applicable sensors and movement parameters are programmed on each object, and then each is assigned to an alliance. For the purpose of this model, red and blue alliance forces are programmed to interact throughout the scenario.

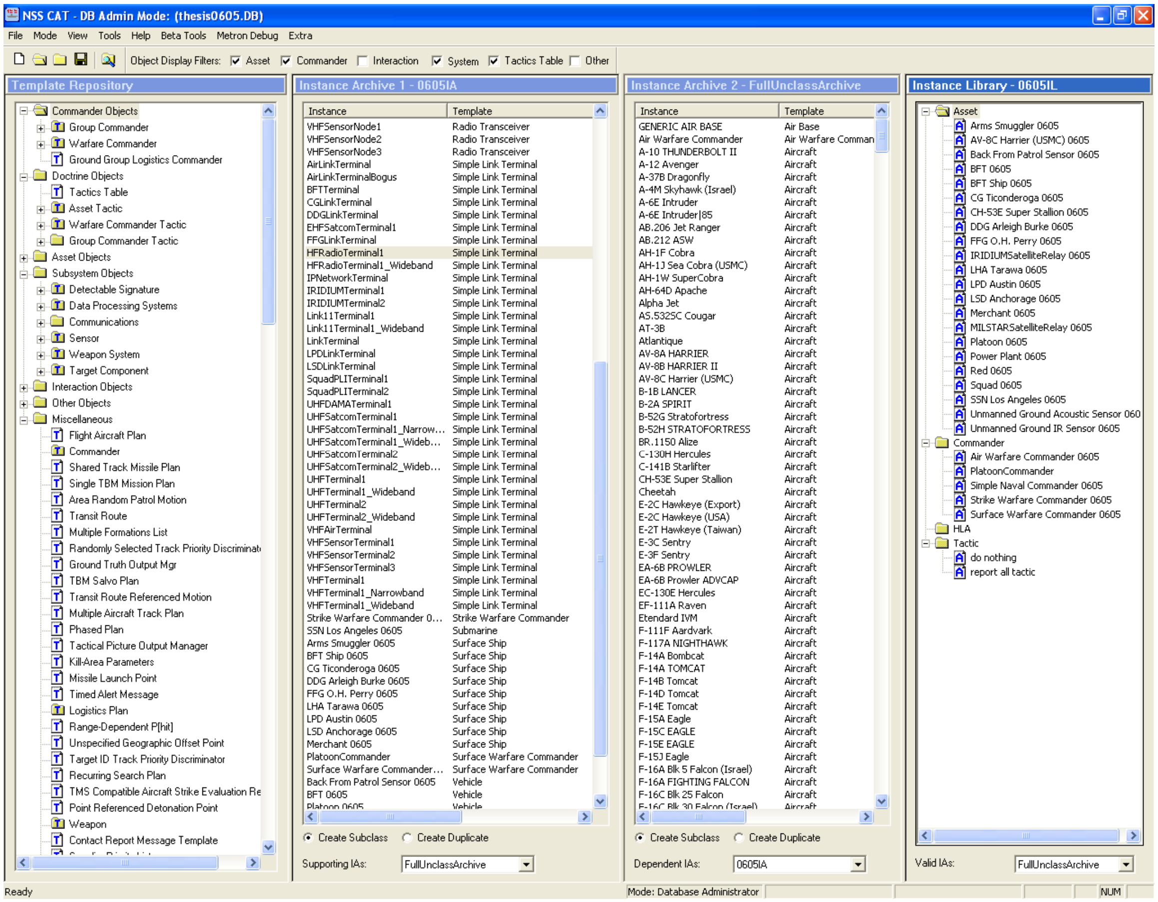

Figure 4. NSS Database Manager Mode

2. Communication Model Development

a. NSS Communication Model

The following discussion describes the communication plan representation by a routed communication plan spreadsheet and can be omitted on first reading. All terms and programming procedures are detailed in the NSS v3.3 Analyst Guide [Stevens02].

(1) Terminals and Nodes. Link Terminals and Network Nodes are built onto each object that communicates within its alliance. Each network connection to an object requires a dedicated Link Terminal and Network Node. There cannot be a Terminal or Node with the same name on the same object, but there can be multiple Terminals and Nodes with the same name associated with the same network on different objects. Customized transmission delay, using minimum and maximum delay or transmission rate and message size, is available for each Link Terminal connection.

There are three types of Network Nodes, Radio Transceivers, IP Communications, and Point-to-Point Nodes. Radio Transceivers are instantaneous transmission nodes where all bandwidth of the network is used for simplex communication and no collisions occur. The specification of frequency bands for each node looks to be a future implementation and is not available on this version of the NSS program. IP Communication nodes have no attributes. IP network bandwidth attributes are applied in the routed communications input spreadsheet. Point-to-Point nodes require a specified number of simultaneous transmissions, similar to a telephone network.

(2) Routed Communication Plan. The NSS model design utilizes the Terminals and Nodes to implement a routed communication plan. The routed communication input file is a tabbed Excel spreadsheet. Each of the seven tabs define a different segment of the input plan for a specified alliance.

Address Groups designate collective address names for groups of individual asset objects that can be used anywhere the name of an object is required. Address Groups are used in the communication plan tab when the group of assets defines a network segment destination.

The **Network** tab defines each communication link between objects with a unique name and network type. Network types are either IP Network, Broadcast or Point to Point. An IP Network is used for links that will have simultaneous transmissions dependant on a defined bandwidth in bits per hour. A Broadcast network allows simplex communication, one message at a time and all members of the network receive all transmissions. A Point-to-Point network is designated to simulate a telephone link where one transmitter object is connected to one receiver object with a defined number of messages allowed at one time. Equipment compatibility is not used in this model; it defines an equipment type label for the network. Sender Aware of Connection Success is used in Point-to-Point networks. Band is not used in this model; it defines the network frequency band being simulated.

CCP tab assigns the Terminal and Node objects previously defined for each object on to a defined network. Each terminal and node can only be assigned once per asset.

Message Template tab is where a unique name, type, size, preparation and transmission delay and message priority can be defined for each message detection type. Message types consist of Contacts, which are raw sensor messages, Tracks, which are fused contact data, General, that are command and control messages, and Ack, that are General or Track message receipt acknowledgements.

The **Message Group** tab assigns message template types into groups that can be used in the communication plan.

The **Comms Plan** tab defines specific routing for message types. A Comms Plan Element (CPE) is created for each route a message takes from originator thru any relays to each segment destination. There are four types of CPEs; Track or Contact reports caused by an asset tactic, Track or Contact reports caused by a warfare commander tactic, command and control (C2) messages caused by a commander tactic, and C2 messages for a commanded asset. Acknowledgments are required for C2 messages for a commanded asset. A Qualifying Destination must be filled in signifying the ultimate receiving asset for all CPE except for contact track reports that are caused by asset tactics. A route is one or more uniquely named element(s) of the CPE having a designated precedence, and acknowledgment details dependent on message type. Additional routes in a CPE can be used for simulated redundant circuits carrying the same message type. There can be one or more Segment Networks for each route. The Segment Network is the name of the network for the route segment terminated or relayed to another segment through the Segment Destination. Designate a Terminal if the message will be relayed from the destination to another CPE having an alternate destination, enabling each destination to process a local track from the contact report. This relay method is not source routed and requires the relay CPE have an intermediate sender listed. IP Latency tab defines the amount of time an IP message takes between land and surface asset types. The default latency is 20ms that is typical for wired networks. In this model, 110ms is used for land and surface connections, and 220ms is used for satellite relay connections.

The **Network Parameters** tab defines additional background traffic, any denial of service degradation of a single IP network, and operational picture corruption. Each parameter is required for to complete the communication plan. These

parameters would introduce additional that was above the scope of this experiment. Track Update rate tab defines a specified rate per hour that track updates occur for stationary assets according to asset type. In this model, all stationary assets with sensors update detected tracks every 15 minutes.

3. Blue Force Tracking Objects

A Blue Force Tracking (BFT) system is a critical command and control element to employment of combat forces. The common force tracking application employed by the MEU uses C2PC over a line-of-sight wideband UHF data network or the Iridium satellite network. The maritime example in this scenario employs the ESG assets feeding GCCS-M tracks over line-of-site UHF Link 11 circuits. These BFT element examples are created for this simulation model.

For each blue alliance asset created there is a mirror BFT object with attached magnetic sensor that detects the parent object magnetic vulnerability and a communication terminal and node that transmits the BFT sensor detections, contact and track reports instantaneously to the parents object. The blue alliance asset relays this track information through the respective Position Location Indicator (PLI) system, for ground forces or Link 11 network for maritime forces. The LHA receives the contact and track reports and then transmits the reports to each of the other units for a common operational picture of friendly force information and locations. Measurement of this network insures that the physical links associated with each object are of sufficient bandwidth to handle the capacity demands placed on them by the BFT system.

4. Unmanned Ground Sensor Objects

To conduct covert missions, Special Operations Forces have identified a need for unmanned ground acoustic and infrared sensors. These sensors have the ability to detect and image objects that move within their specified detection range. The data that is collected by each sensor is transmitted to a nearby observer through a VHF data network. The contact data can be entered into a tracking system and the imagery data can be transmitted to a regional intelligence center for processing.

In this scenario model, there are three sensors, one acoustic and two infrared imagery sensors, which are used to detect and identify targets in the red alliance camp and on the roads. The Back from Patrol (BFP) Ground Acoustic Sensor 01 is used to

send a large amount of imagery data to LHA at a specified time after the compound raid on the suspect training camp. The need to differentiate between large and small message sizes is necessary to obtain a way to increase or decrease message load through the sensor data paths. We accomplish this by programming different types of sensors that produce message of different size and increase or decrease the number of sensor detections throughout the scenario.

I. SCENARIO DEVELOPMENT LESSONS LEARNED

This section details lessons learned while crafting the NSS scenarios for this experiment. Future investigators may find these helpful when extending this research.

1. When making objects, check instances for fusion centers so assets are able to relay sensor detections as contact reports and also have the ability to create local tracks. Also, check Red alliance instances for damageable components for battle damage assessment determination.

2. Assign a Warfare Commander to the Platoon Commander asset so maneuvering squads can be assigned identification and engagement orders directly from the field units instead of from Strike Warfare Commander attached to LHA.

3. To keep BFT sensors in close proximity to the parent asset, create a formation movement plan for maritime instances. Formation movement plans are unavailable for land objects. To alleviate this limitation, BFT objects associated with each asset have identical movement plans. Although, when the platoon commander orders squads for identification and track and trail tactics, a squad will move away from the planned patrol areas simulating covert action and will not update their respective track while assigned to intercept unidentified tracks.

4. Assign a Platoon Commander tactic to relay all local tracks for track updates that go to all assets during the terminal air strike operation. This allows increased probability of kill of Red forces by AV8 Harrier. To also increase probability for Red kills the minimum and maximum movement speed for each asset assigned to an area, needs to decrease so Blue forces can engage Red targets for a successful track and trail tactic.

J. QUANTITATIVE ANALYSIS MEASURES

Selection of effectiveness measures is an essential step in performance analysis of any C4I system. This analysis is used to identify improvement alternatives in the system design. It is recognized that a single definition of performance measures does not exist, and the determination of both performance and effectiveness of C4I systems has proven to be a complex problem.

This thesis will focus on measures of system performance related to communication system message load characteristics, and behavior such as, timeliness or accuracy. To provide the means for analysis of force effectiveness, as the scenario progresses Red alliance attrition will be measured and related to system performance measures to identify any correlation with the scenario timeline. To gather these performance and attrition measures, relevant predefined MOEs are selected from existing database in the NSS program and programmed to specific asset characteristics.

1. NSS Configurable MOEs

Short descriptions of available measures that relate to communication networks are provided in Appendix B. Each measure has receiver, sender, asset and sampling conditions, or breakdown lists, which can be selected and modified dependent upon the communication plan definition for each asset. Multiple measures can be assigned to each communication link, applied with different measurement conditions.

2. Applied NSS Measures

A predefined set of attrition MOEs is used to determine the effectiveness of force applied when a track and trail tactic is assigned to air assets for target updates. The remaining MOE types are user defined and determine message loading and delay on each network in the communication plan. Each of the MOEs is based on the number of messages sent and received at a specific Terminal attached to an object. One MOE counts the total of all messages sent and received throughout the scenario. BFT messages sent and received are counted in a separate MOE to enable troubleshooting of possible communication network anomalies. Communication message loading determines the time average number of messages at a specified object or associated terminal and is only used for IP networks. This MOE is used for the IP network and Iridium network in the model.

Figure 5 summarizes the NSS MOEs used in the model to analyze communication loading, delay and attrition associated with the network names pictured in Appendix D.

MOE Name	MOE Type	Network Name
ESG IP Message Loading [# of msgs]	Number Comms Load	IP Network
ESG CG IP Message Loading		
ESG DDG IP Message Loading		
ESG FFG IP Message Loading		
ESG LHA IP Message Loading ALL0029-0049_1sec		
ESG LHA IP Message Loading		
ESG LPD IP Message Loading		
ESG LSD IP Message Loading		
ESG SSN IP Message Loading		
IRIDUIM IP Message Loading PltCDRTerm1_Incoming		PLTCDR Iridium ETCS
IRIDUIM IP Message Loading PltCDRTerm1_Outgoing2730-2740_1sec		
IRIDUIM IP Message Loading PltCDRTerm1_Outgoing		
IRIDUIM IP Message Loading PltCDRTerm1_Outgoing4423-4443_1sec		
IRIDUIM IP Message Loading PltCDRTerm2_Incoming		
IRIDUIM IP Message Loading PltCDRTerm2_Outgoing		
IRIDUIM Message Loading SatelliteTerm1_Incoming		PLTCDR Iridium ETCS
IRIDUIM Message Loading SatelliteTerm1_Outgoing		
IRIDUIM Message Loading SatelliteTerm2_Incoming		LHA Iriduim ETCS
IRIDUIM Message Loading SatelliteTerm2_Outgoing		
LHA IRIDIUM Term1 IP Message Loading_Incoming		
LHA IRIDIUM Term1 IP Message Loading_Outgoing		
Message Receipt Delay BFP-LHA	Average Total Delay at Final Destination	VHF Sensor 01
Message Receipt Delay SQD-PltCDR		UHF/VHF Intersquad
Message Receipt Delay SQD-LHA		UHF/VHF Intersquad, UHF SATCOM MEU TAC, Iridium ETCS, MEU TAC HF
Message Receipt Delay LHA BFT		UHF Link 11
Message Receipt Delay BFT DDG - LHA		
Message Receipt Delay ESG - LHA Contact/Tracks		IP Network
ESG CMD Msgs Sent	Message Send	UHF SATCOM MEU CMD, UHF DAMA ESG CMD
MEU CMD Wideband Satcom Msgs Sent		UHF SATCOM MEU CMD
MEU CMD Satcom Msgs Sent		
MEU TAC HF Msgs Sent		MEU TAC HF
MEU TAC Wideband HF Msgs Sent		
MEU TAC Narrowband Satcom Msgs Sent		UHF SATCOM MEU TAC
MEU TAC Wideband Satcom Msgs Sent		
MEU TAC Satcom Msgs Sent		
MILSTAR Voice Msgs Sent		Future Development and Testing
SCC C&R UHF Wideband Msgs Sent		UHF SCC C&R
SCC C&R Messages Sent		
UHF Wideband InterSquad Msgs Sent		UHF Intersquad
UHF InterSquad Msgs Sent		
VHF Wideband InterSquad Msgs Sent		VHF Intersquad
VHF InterSquad Msgs Sent		
VHF Narrowband InterSquad Msgs Sent		
UHF Wideband Link 11Msgs Sent		UHF Link 11
UHF Link 11Msgs Sent		
VHF Air Control Msgs Sent		VHF Air Control - Future Development and Testing
VHF Acoustic Sensor2 Msgs Sent		VHF Sensor 2
VHF BFP IR Sensor1 Msgs Sent		VHF Sensor 01
VHF IR Sensor3 Msgs Sent		VHF Sensor 3
BFT Land Msgs Received LHA	Message Received	Squad 01 PLI, Squad 02 PLI, Iridium ETCS
BFT DDG Ship Msgs Sent	Message Send	UHF Link 11
BFT Ship Msgs Sent	Message Send	
Asset Destroyed_1	Attrition Asset Destroyed	Attrition
Aircraft Cumulative Launches_1	AIRCRAFT LAUNCHES	Aircraft Launches
Aircraft Available_1	Aircraft Available	Aircraft Available
Messages Received_1	Message Received	All Networks
Messages Sent_1	Message Send	All Networks

Figure 5. NSS MoE Summary

K. EXPERIMENT EXECUTION

1. Analysis Process

The NSS employs a Study Management mode to execute the specified number of Monte Carlo simulation replications and automatically collect desired MOEs for export to formatted Microsoft Excel spreadsheets. The MOE data is exported in two types of files, an average summary and individual MOE output for each run. Average values are calculated for each MOE and summarized in one file, while the other file contains each individual MOE value generated per a programmer specified sampling rate for that MOE.

The scenario design dictates that data from multiple excursions with communication architecture changes be used in the experiment. By only changing the communication architectures, excursion analysis allows for increased control of the experiment. To exercise the Monte Carlo approach afforded by NSS each excursion is executed seven times with different random number seeds. The same seven seeds are used for each excursion. Also, MOEs for each excursion stays the same throughout the study.

We design seven different communication plan excursions, a baseline plan and six alternatives, to determine if changes in communication performance occur. Each excursion differs from the others only in the amount of bandwidth allowed for the circuits. To focus the experiment we will analyze only Sent Messages and Message Receipt Delay MOEs on the circuits used by the DO command structure. This allows a comparison of network communication load and message receipt delay during critical events in the scenario.

The primary communication links being analyzed for communication load are the Iridium network, passing Blue Force Track (BFT) messages, and MEU TAC SATCOM circuit with contact and track reports being passed from the deployed Platoon Commander. Message Receipt Delay measurement looks at all networks that carry contact and track reports from unmanned sensors and squads through the Platoon Commander for relay to the Strike Warfare Commander on the LHA.

2. Baseline Communication Plan

The baseline plan includes all networks and circuits in the communication model. The bandwidth of the Iridium IP network is set at 24K bits per second (bps). The

bandwidths of the broadcast networks are all set at a default 1.5Mbps as shown below in Table 1. This gives the communication plan an overall bandwidth greater than 7Mbps for all message types. With this open bandwidth scheme, we assume that all messages generated by the sensors and all orders from warfare commander assets will be received at their final destinations in a minimal amount of time.

Network Name	Asset Terminal Name	Terminal Bandwidth (bps)
MEU TAC HF	HF Radio Term1	1.5M
UHF Link 11	Link 11 Term	1.5M
UHF Intersquad	UHF Term1	1.5M
SCC C&R	UHF Term2	1.5M
MEU TAC	UHF Satcom Term1	1.5M
MEU CMD	UHF Satcom Term2	1.5M
VHF Intersquad	VHF Term1	1.5M

Table 1. Baseline Bandwidth Settings

3. Limited Iridium

The Limited Iridium excursion includes all networks in the communication model. The only deviation from the Baseline is the bandwidth of the Iridium IP network is now constrained at 6Kbps. The bandwidths of the broadcast networks are all still at the default setting of 1.5Mbps. This also gives the communication plan an overall bandwidth for all message types at greater than 7Mbps. With this bandwidth scheme, we investigate if a constrained IP network sending BFT messages over the Iridium network effect communication MOEs.

4. Limited Iridium Wideband

The Limited Iridium Wideband case includes all networks in the communication model. The bandwidth of the Iridium IP network is constrained at 6Kbps. The bandwidths of the broadcast networks assigned to Blue Force Tracking and unmanned sensor circuits are at the default setting, but all other primary broadcast communication paths are constrained as shown below in Table 2.

Network Name	Asset Terminal Name	Terminal Bandwidth (bps)
MEU TAC HF	HF Radio Term1	2.8K
UHF Link 11	Link 11 Term	6.0K
UHF Intersquad	UHF Term1	6.0K
SCC C&R	UHF Term2	6.0K
MEU TAC	UHF Satcom Term1	25K
MEU CMD	UHF Satcom Term2	25K
VHF Intersquad	VHF Term1	30K

Table 2. Limited Iridium Wideband Case Bandwidth

These bandwidth changes are applied at the network terminals for each asset connected to that network. This case gives the communication architecture an overall bandwidth for all message types at 79Kbps. With this bandwidth scheme, we investigate if constrained contact and track reports over the broadcast radio networks, as well as messages over the Iridium network effect communication MOEs, and if this communication limitation affects Red alliance attrition.

5. Limited Iridium Narrowband

The Limited Iridium Narrowband excursion is similar to the previous wideband case except the primary broadcast network bandwidths of MEU TAC, MEU CMD and VHF Intersquad are continually constrained as shown below in Table 2.

Network Name	Asset Terminal Name	Terminal Bandwidth (bps)
MEU TAC HF	HF Radio Term1	2.8K
UHF Link 11	Link 11 Term	6.0K
UHF Intersquad	UHF Term1	6.0K
SCC C&R	UHF Term2	6.0K
MEU TAC	UHF Satcom Term1	**6.0K**
MEU CMD	UHF Satcom Term2	**6.0K**
VHF Intersquad	VHF Term1	**16K**

Table 3. Limited Iridium Narrowband Case Bandwidth

This case gives the communication architecture an overall bandwidth for all message types at 46Kbps. With this bandwidth scheme, we continue to decrease bandwidth while keeping the same message volume during each simulation excursion.

6. No Iridium

In this case, we remove the Iridium network from the communication model, simulating a drop in satellite connectivity. The bandwidths of the broadcast networks are

all again at the default setting of 1.5Mbps. This again gives the communication plan an overall bandwidth for all message types at greater than 7Mbps. To continue to provide an alternate communication path for contact and track reports, we configure the MEU TAC HF network as a secondary circuit to the MEU TAC Satcom link for these message types. With this configuration, we are investigating if the removal of the Iridium network effects communication MOEs.

7. No Iridium Wideband

In this case, we also remove the Iridium network from the communication model. The bandwidths of the broadcast networks are the same as in the Limited Iridium Wideband case. The primary broadcast network bandwidths are constrained as shown in Table 2 above. This case gives the communication architecture an overall bandwidth for all message types of 76Kbps. This scheme continues to decrease bandwidth with the removal of the Iridium network and the limitation of the MEU TAC HF radio circuit. With this bandwidth constraint, we are investigating if contact and track reports over only the broadcast radio networks effect communication MOEs, and if this communication limitation affects Red alliance attrition.

8. No Iridium Narrowband

In this final case, we also remove the Iridium network from the communication model. The bandwidths of the broadcast networks are the same as in the Limited Iridium Narrowband case. The primary broadcast network bandwidths are constrained as shown in Table 3 above. This case gives the communication architecture an overall bandwidth for all message types of 43Kbps. This scheme continues to decrease bandwidth with the removal of the Iridium network and the significant limitation of the MEU TAC HF radio link. With this final bandwidth constraint, we continue to investigate the effects of communication MOEs, and determine how this final limitation affects overall force effectiveness.

Communication Architecture	Overall System Bandwidth
Baseline	7524Kbps
Limited Iridium	7506Kbps
Limited Iridium – Wideband Terminals	79.0Kbps
Limited Iridium – Narrowband Terminals	46.0Kbps
No Iridium	9000Kbps
No Iridium – Wideband Terminals	75.8Kbps
No Iridium – Narrowband Terminals	42.8Kbps

Table 4. Summary Table of Alternate Cases

L. SUMMARY

The above sections describe how the NSS model was designed and built to execute the experiment based on a scenario utilizing the DO concept and ESG command and control structure. During the development, many programming challenges were identified and the model was molded to reduce these limitations and remain within the bounds of the study. The detailed analysis plan identifies performance measures used to compare seven excursions with decreasing bandwidth constraints. The next chapter outlines results from the measures and provides findings that are related to the thesis questions.

IV. RESULTS

A. INTRODUCTION

We present the results in this chapter by answering the three thesis questions through graphical observation amplified by statistical testing of an attrition data sample. To identify any differences in attrition, message delay, and message load, each model excursion is compared to the baseline while being related the to scenario timeline. If differences in attrition between excursions are realized, we investigate if they can be attributed to communication delays and message load. The last step is to correlate the findings with the problem statements to form conclusions that will be covered in the next chapter.

With NSS in study mode, we use initial runs of the scenario for troubleshooting problems associated with the simulation's communication plan elements. Then, with the communication plan and asset terminal errors corrected, we obtain the production runs from each communication architecture excursion. The cases are characterized by progressively constrained bandwidth within the communication plan as described in Chapter III. Each case has ten independent Red alliance targets to ensure that sufficient MOE data is collected to highlight any measurable results. We compare average MOE data from each case graphically to determine similarities and significant differences. We then match larger differences with the simulation scenario events to determine tactical significance of the bandwidth limited case modifications.

B. COMMUNICATION ARCHITECTURE IMPACT ON FORCE EFFECTIVENESS

1. Overview

The NSS study management mode generates the average attrition MOE data as the number of targets destroyed over a specified sample time. For the scenario crafted for this study, up to ten enemy targets could be destroyed. Useful attrition data is only collected during the air strike phase of the scenario. Although the alternate hypothesis is that at least one excursion (communications architecture) would produce markedly different force attrition, our intuition was that there may be a somewhat linear relationship such that as bandwidth decreased, so would force attrition.

2. Experimental Results

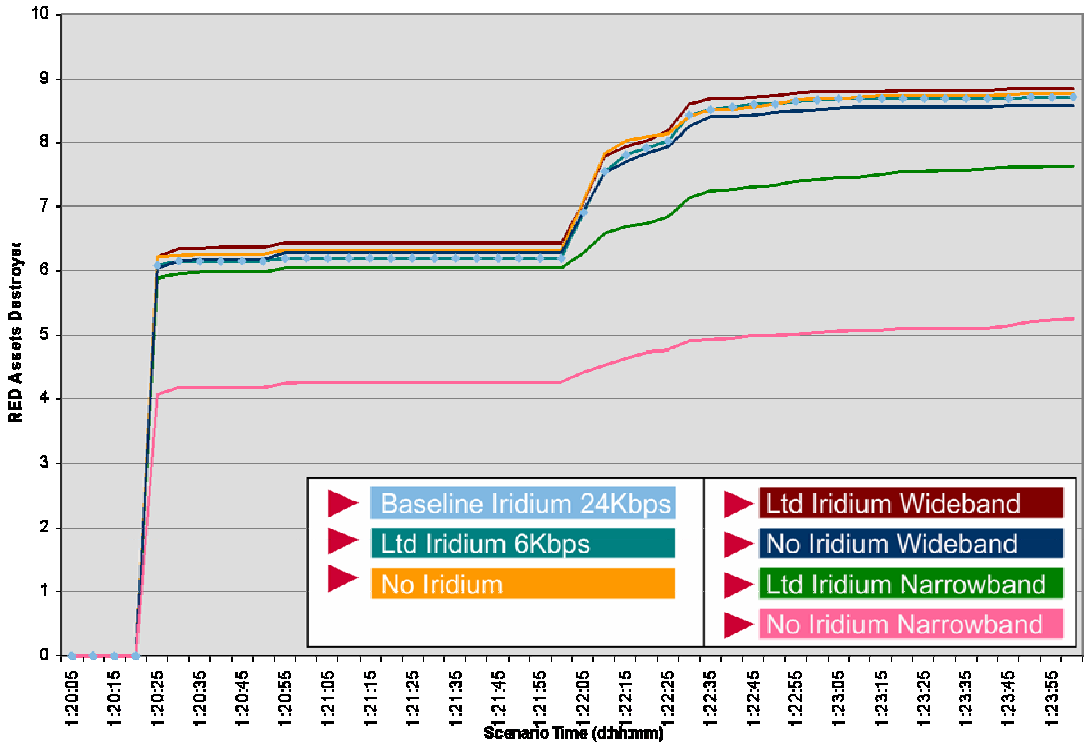

Figure 6. Cumulative Average Attrition – 100 Replications

The graph shows an ability of the NSS to identify the lack of attrition due to incomplete mission success after the initial sortie of strike aircraft. The aircraft are programmed to loiter until their ordnance is exhausted or until fuel becomes low. While loitering, the aircraft can continue to affect damage when track updates are received from the Strike Commander or DO Platoon Commander. When the aircraft recover and refuel they are available for tasking again by the Strike Commander with updated Red alliance track information. With updated position data strike aircraft will continue the attrition of Red tracks until recalled at the end of the scenario.

The bandwidth limited excursions show a decrease in cumulative attrition, primarily between the narrowband cases where the bandwidth was most restrictive. The data also shows no significant difference between wideband cases and the remaining excursions. An analysis of the end-state attrition data will prove at least one of the excursions is different, showing changes in force effectiveness.

3. Analysis

To determine the significance of our observed differences among different architectures, we conducted an analysis of variance between excursions' end-state attrition observations. Our working (null) hypothesis is that all seven architectures produce end-state data with the same mean attrition. Our alternate hypothesis is that at least one communication architecture excursion demonstrates significantly different attrition. ANOVA results in Table 5 clearly support rejecting the null hypothesis, with the No Iridium Narrowband clearly showing significantly different end-state attrition.

```
Source  DF      SS     MS      F      P
Factor   6  154.00  25.67  18.59  0.000
Error   42   58.00   1.38
Total   48  212.00

S = 1.175   R-Sq = 72.64%   R-Sq(adj) = 68.73%



Level                     N   Mean  StDev
Base Line                 7  8.714  1.113
LTD Iridium               7  8.714  1.113
LTD Iridium Wideband      7  9.429  0.787
LTD Iridium Narrowband    7  9.429  0.787
No Iridium                7  9.286  1.113
No Iridium Wideband       7  9.286  0.756
No Iridium Narrowband     7  4.143  2.035


 Individual 95% CIs For Mean Based on Pooled StDev

Level                     ----+---------+---------+---------+-----
Base Line                                        (----*---)
LTD Iridium                                      (----*---)
LTD Iridium Wideband                                 (---*----)
LTD Iridium Narrowband                               (---*----)
No Iridium                                          (---*----)
No Iridium Wideband                                 (---*----)
No Iridium Narrowband     (----*---)
                          ----+---------+---------+---------+-----
                            4.0       6.0       8.0      10.0

Pooled StDev = 1.175
```

Table 5. ANOVA results from Architecture versus End-State Attrition

4. Findings

Although we were able to reject the null hypothesis, the covariance between bandwidth and force attrition was not very strong. The observed attrition results did not decrease linearly with decreasing bandwidth. Although the No Iridium Narrowband excursion (an extremely low throughput case) demonstrated significantly weaker force attrition, all other cases were statistically identical in mean attrition. These architectures, with throughputs ranging from 42.8 Kbps to over 7000 Kbps (Table 4), show a relatively flat response in force attrition.

The weakness of the relation between throughput and attrition may be due to a number of reasons. First, the communication plans crafted for this research and incorporated into NSS may have lacked sufficient detail (e.g., background traffic) to physically recreate realistic communications loading. More likely, the scenario may not have been sensitive enough to detect small changes in throughput; a single attrition event, an air strike, was used in the scenario and became a single measure of all communication events that may have had an effect on force effectiveness within any one realization.

Having established that we can produce meaningful changes in force attrition based on the communications architecture, we next investigate the communication performance differences among architectures in terms of message delay and message loading.

C. COMMUNICATION ARCHITECTURE IMPACT ON COMMUNICATION SYSTEM PERFORMANCE

1. Overview

Given the relatively poor performance of the Narrowband cases, we might expect that internal communications systems metrics (message delay and message loading) clearly correlate to the poor force attrition. In this section, we examine these communications metrics with respect to each of the communications architecture (excursions).

Within the scenario, we generate most of the sensor data at about the same points in the simulation timeline depending on Red force movement. Command and control messages generated by Warfare Commanders in response to specific events depend on the timeliness of the sensor data as the scenario unfolds. Across all excursions, the

expectation is that message delay should increase with decreasing bandwidth. Also, as the tactical situation dictates more throughput at certain assets, the message delay between units should increase. This delay may effect overall mission effectiveness due to an increase in the time for Red alliance track updates to be recognized by the air strike assets. The analysis of communication performance results focuses on the four cases where the bandwidth was constrained from the baseline.

a. Blue Force Track Communication Load Impact

The Blue Force Track (BFT) reports are programmed in the NSS scenario to update every 15 minutes on stationary targets. Therefore, message traffic will increase during the sample time on the IP Network and UHF Link 11 when reporting ship positions at the 15 minute interval. Minimal message delay in these networks is expected. The frequency of ground force BFT reports is dependant on movement of the tracked asset by the BFT sensor. Each time the asset turns, a track update message is sent through the position location information (PLI) and Iridium networks relayed through the Platoon Commander to the Warfare Commander on the LHA. Therefore, the random movement generates increased message traffic through this network and when assets are in small maneuver areas, such as the rally area after the camp raid, an increase in BFT message volume is expected.

Keeping with the stochastic nature of simulation, we expect the remaining networks to show random message generation within the tactical situation constraints of the NSS scenario. We expect an increase in message traffic will occur after the camp raid when the ground units process the bandwidth intense imagery data prior to the air strike event. An increase in message volume is also expected during scenario specific events, such as, when ground forces continuously update hostile tracks to the air strike assets in response to Platoon Commander track and trail orders.

2. Experimental Results

a. Communication Delay

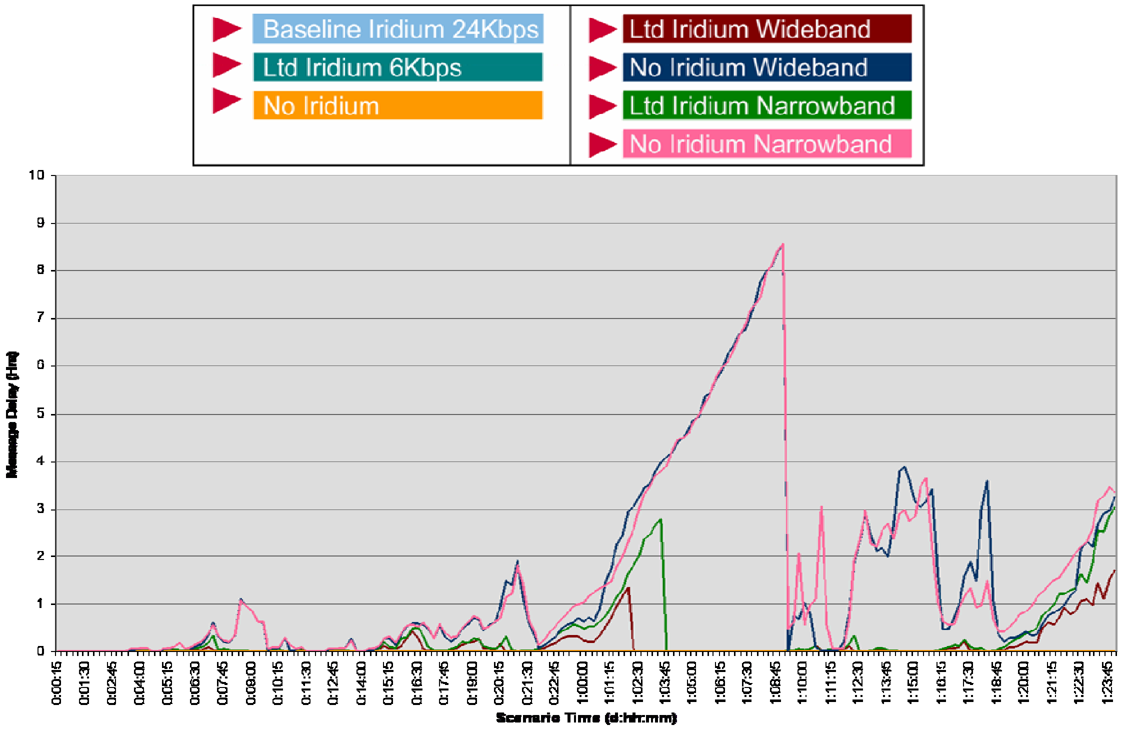

Figure 7. Squads to LHA - Average Message Receipt Delay (Complete Scenario)

For each excursion, seven runs were made, and the average message delays over the two-day scenario are depicted in Figure 7. These track and contact update message delays, referred to within NSS as the Total Delay at Final Destination MOE, are measured on the communication link between the Squads through the Platoon Commander relay to the LHA. Of interest is if the MOE shows the existence of a delay which we can correlate with the tactical situation. Such a situation occurs when the Squads and Platoon Commander send large data files to the LHA after an intelligence gathering raid on the suspected terrorist camp. The communication model is programmed to transmit these large messages in a short amount of time, but in both Wideband and Narrowband No Iridium architectures, this causes a significant increase in delay with a sharp fall-off when the last message is received eight hours later. Note that the first three

cases where minimal bandwidth limitation is programmed, no message delays are realized on the graph. This event appears in Figure 7 at 1:04:00.

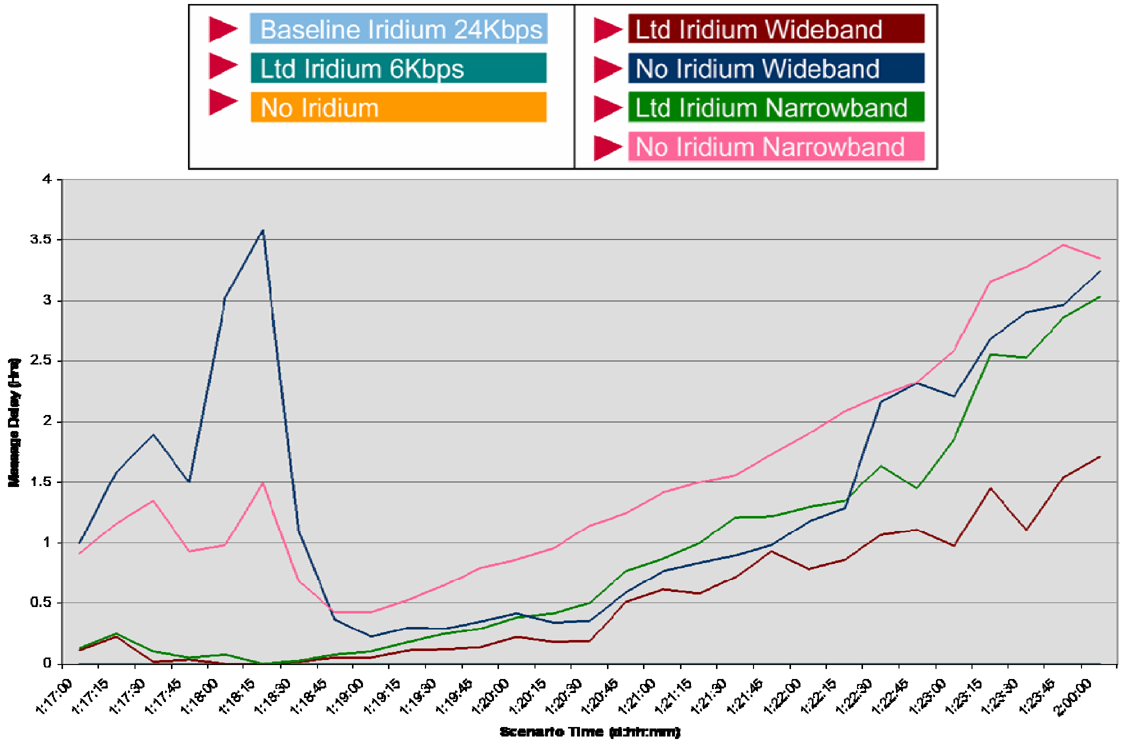

Figure 8. Squads to LHA – Average Message Receipt Delay

This graph represents a slice of the contact and track update message delay MOE. We generate this data at the end of the scenario to emphasize the impact of message delay on attrition during the air strike phase. As expected, messages in the Narrowband case take longer to get to their destination for action by the Strike Commander than in the Wideband case. We also note that without Iridium, message delay increases overall due to the lack of bandwidth on the TAC HF alternate data circuit being used to transmit contact and track reports. The graph also shows that some messages generated by sensors to update Red alliance positions do not arrive at the LHA by the end of the scenario to effect action by the assigned air strike.

b. Communication Load

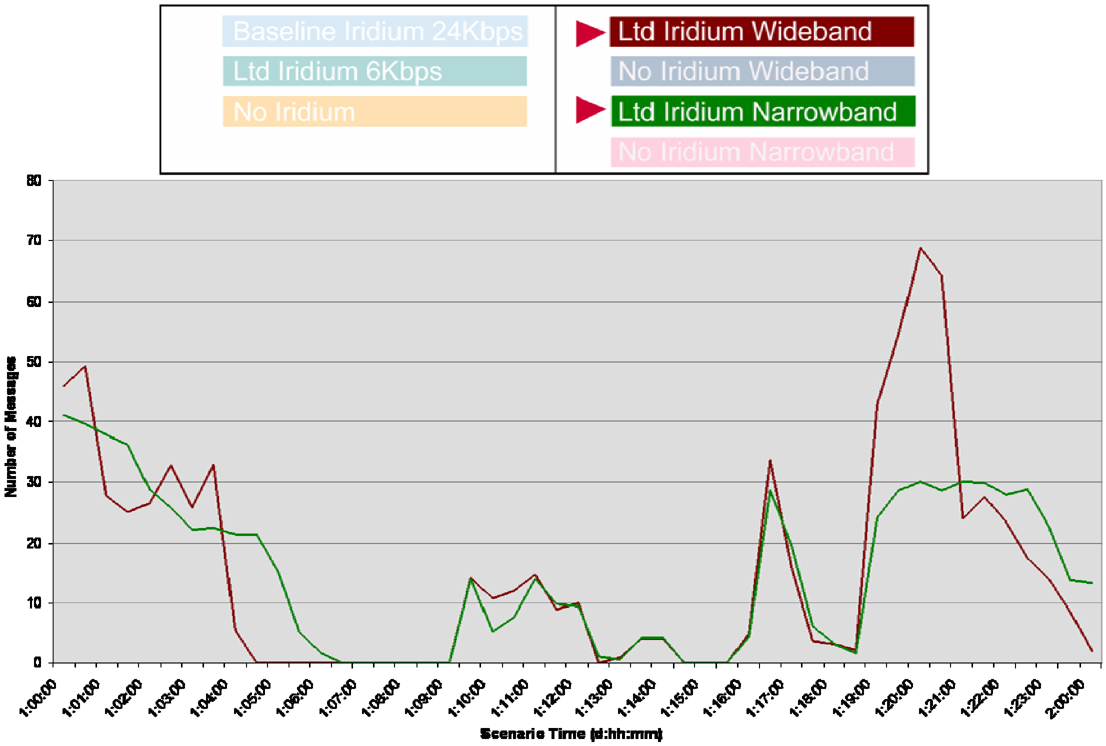

Figure 9. Satcom MEU TAC – Average Messages Sent MoE

Figure 9 represents instances of an increase in message load at tactically significant events from the intelligence gathering raid at 1:04:00 through the air strike at 1:21:00 in the scenario at the limited bandwidth MEU TAC circuit between the Platoon Commander and the LHA. This message load increase verifies a cause of message delay during the same tactical events in Figure 7. Comparison of the two cases (Limited Iridium Wideband and Narrowband) can also show message receipt delay at 1:05:00 and 1:22:00. Around these time periods there is a decrease in messages sent but the same number of messages in the Limited Iridium Narrowband case are required therefore it takes longer for the messages to get to their destination.

3. Findings

Our comparison of message delay among the different communications architectures shows a moderate relationship between the available bandwidth and delays (Figure 7). These correlations are especially apparent during the air strike portion of the

scenario (Figure 8). These differences are not based on simple link budgeting, however; further analysis of the messages sent (Figure 9) demonstrates that certain architectures require additional messaging to accomplish scenario objectives. These non-linear effects are discernible, in part, because of the added richness in the scenario with the routed communications feature of NSS.

D. UTILITY OF NSS

1. Overview

As a course of action decision and analysis tool, the NSS proves its use during previous experimentation. With the new routed communication modeling capability and associated MOEs, the expectation of the tool to demonstrate communication system performance metrics was high. The possibility that this assessment of combat effectiveness could be attributed to these metrics was not clear due to user community inexperience and lack of similar studies.

2. Findings

Given a scenario of medium complexity (ESG) and small communications architecture (less than 100 nodes), we show that the NSS has the ability to demonstrate changes in combat effectiveness as a result of associated changes to communication architecture that impact communication performance. Significant study of the NSS Analyst Guide and many hours of trial and error made programming the model scenario with routed communication capability very time intensive. It is highly recommended that any further studies with the NSS utilize experienced operators for model design assistance.

E. SUMMARY

In this analysis, we present the results by graph observations with statistical testing of attrition data. We identify differences and correlate relationships between attrition, message delay and message load within excursions relative to the scenario. We then use these results to answer the thesis questions concluding with recommendations of the usefulness of the modeling program. Next, we will use this data analysis to present conclusions and recommendations for further study.

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V. CONCLUSIONS AND FUTURE WORK

A. SUMMARY

This thesis shows the ability of the NSS to model how changes in communication architecture for a given scenario contribute to combat effectiveness. The scenario used for this study models communication plans associated with a distributed operations mission from an ESG. The simulation model experiment contains seven communication architectures with progressively reduced bandwidth capacity. Each architecture excursion has the same scenario timeline and measurement parameters. The results of each excursion are graphically compared and statistically analyzed to identify communication performance impacts at critical events throughout the scenario. A correlation is made with communication performance and combat effectiveness when the enemy force attrition is compared over each excursion to identify if a decrease in combat effectiveness can be seen as a result of reduced communication capability.

B. CONCLUSIONS

The examination of the results determines the answers to the questions posed in the thesis problem. For ease of understanding, the findings to answer the three questions are summarized below in reverse order. The average attrition data did not decrease linearly with decreasing bandwidth as expected. In the most constrained bandwidth case there is a statistically significant difference in attrition. Therefore, the NSS shows the ability to reflect the impact of communication system performance on force effectiveness.

The visual comparison of the graphical representations of message load and message delay MOEs determines a moderate relationship between the communication architectures and the MOEs along the scenario. By comparing the time traces it is evident that there exists a correlation between communication system measures of effectiveness and force effectiveness. Therefore, the NSS shows the ability to generate data that reflects changes in communication system performance due to changes in the communication architecture. The NSS was successful in giving this communication system model a strategic focus that provided the ability to show military significance of bandwidth differences between communication architectures.

Finally, it is the author's opinion that the NSS is a very useful tool for course of action analysis and to study force effectiveness impacts of sensor configurations. To study force effectiveness impacts of communication system architectures, the routed communication capability requires significant granularity in the communication model.

C. FUTURE WORK

This thesis provides a general communication system evaluation procedure using the NSS with a medium force level (such as an ESG force model). To fully integrate this modeling and simulation into FORCEnet development, future research should be conducted to increase communication model granularity in the NSS.

Further communication model development should increase accuracy in communication throughput characteristics. The refinement of the characteristics of specific network links and terminals programmed to each object will better define the communication plan. The expansion of the tactical scenario to include white shipping traffic and the introduction of enemy ships to detect and track will also make the model more realistic.

To increase the fidelity of attrition based warfighting modeling and simulation tools, like NSS, federation with communication modeling tools can be investigated. Military planners have accepted NETWARS for its ability to accurately model IP and broadcast networks. This data accuracy could be federated with the NSS model to produce not just network specific performance measures, but also allow the NSS to produce strategic mission effectiveness data for the military planner to examine the outcome of scenarios taking into account the advantages gained by having improved communication systems.

APPENDIX A. SCENARIO BACKGROUND

A. SCENARIO STORYBOARD

The coastal nation of Califate has a diverse ethnic and religious pacific population with a major international port that has minimal vessel arrival notice and minimal registration requirements. Califate has a small Coast Guard and only a ceremonial infantry battalion. Local and international private security companies guard most government facilities and major businesses.

The 82 square mile island province of DeLuz is home to native Califites who are 90% Muslim. The DeLuz Islamic Group (DIG) goal is to remove non-natives from Califate and establish an Islamic state. According to CIA reports, DIG fighters have been trained in Afghanistan and Iraq. Despite their small numbers DIG forces have performed brutal attacks killing Califate government officials.

1. Situation

One month ago, DIG captured and killed a US contractor working on the nuclear engineering project for Government of Califate Power Plant. Ten days later, an Al Qaeda released video mentioned DIG as an example of the Islamic world rising to defeat the American, ”evil forces”. A recent CIA assessment shows DIG has received financial and technical training support from major Islamic Terrorist Organizations and that DeLuz is a new front in Jihad. From this assessment and from Senate Intelligence research, the National Command Authority determines the presence of terrorist cells in Califate a threat to U.S. national interests. The President of the United States orders the creation of a Joint Task Force (JTF) to verify and bring those people responsible for the murder of innocent Califate civilians to justice.

One week later an Expeditionary Strike Group (ESG) with embarked Marine Expeditionary Unit, Distributed Operations Capable (MEU(DOC)), positions off the west coast of Califate, and remains outside the heavily traveled North-South shipping lanes. The Task Force Commander’s intent is to prepare to conduct Visit Board Search and Seizure (VBSS) operations with organic Destroyer, air support and Marine Special

Purpose Forces. The commander also intends to prepare to reinforce security for Government of Califate Power Plant that is believed to be a primary DIG target.

2. Mission

To limit forces ashore to only those vital to mission accomplishment, the JTF Commander has directed a Distributed Operations (DO) mission. This mission will conduct operations to confirm the presence of terrorist training activity in the DeLuz Island province, and attack to seize physical evidence of transnational involvement in the Califate region. The mission will be conducted by a specialized DO platoon, which will covertly insert by Rigid Hull Inflatable Boat (RHIB) and distribute squads for observation and reporting of suspected training camp activities. Follow-on operations for the DO platoon may require Unmanned Aerial Vehicle (UAV) mission coordination, direction, and terminal guidance for a precision air strike.

3. Timeline

For a point of time reference to simulation time, D-Day, H-Hour is the simulation start time. For the scenario, it is just after sunset, two days prior to the compound strike on DeLuz Island. The DO Platoon consisting of 16 men in two squads, are covertly delivered by two RHIBs. The RHIBs deploy their troops and supplies and return to the LHA. Squad 01 deploys to a northern vantage on DeLuz with a six-man unit, while Squad 02 deploys to a southern vantage on DeLuz with a six-man unit. The Platoon Commander deploys in a safe landing zone and sets up communication equipment.

D-Day	H-Hour	Event Description
D+0	H+0	Squad 01 establishes a patrol base north and west of the suspected compound. Squad 02 establishes patrol base south of the suspected compound. Platoon CDR establishes Blue Force Tracking (BFT) and performs communication checks with Ground Element Commander in the Supporting Arms Coordination Center (SACC).
D+0	H+3	Squads 01 and 02 deploy two unmanned sensors. One passive detection, acoustic sensor and one still video motion capture, infrared detector. Unmanned sensor communication checks.
D+0	H+4	Sensor 2 detection of Red force.
D+0	H+7	Squad 01 observes truck and foot traffic on adjacent road, transmits the contact report to the Platoon Commander.
D+0	H+8	Squad 01 performs reconnaissance in an area outside the suspected compound
D+0	H+9	Squads 01 and 02 patrol, monitor sensors and resupply. There are

D-Day	H-Hour	Event Description
		random sensor detections from daily foot and vehicle traffic between DeLuz Village, a small port facility and the compound.
D+0	H+21	Squad 01 patrols an area outside the suspected compound.
D+0	H+24	The Execute Order is received from the Ground Force Commander for an intelligence gathering raid in the suspected compound.
D+1	H+0	Squads 01 and 02 execute the compound raid.
D+1	H+4	Squads 01 and 02 proceed to a rally point at the Platoon Commanders position and process photos and documents seized. This information is transmitted to the Ground Force Commander.
		Intelligence items gathered consist of photos detailing weapons, documents, command and control information, personnel strength and the presence of possible non-combatants.
D+1	H+8	Squads 01 and 02 return to respective patrol areas for patrol, monitor sensors, and resupply. There are random sensor detections from daily foot and vehicle traffic between DeLuz Village, the small port facility, and the compound.
		There is increased communications within the ESG in preparation for strike planning.
D+1	H+21	The Execute Order is received from the Ground Force Commander for an air strike of the terrorist compound.
D+2		Squads 01 and 02 observe the compound movement, collect target information, and monitor sensors.
D+3	H-hour	A sortie of AV-8 Harriers is ordered for the air strike, Squad 01 acts as the forward air control for terminal guidance of ordnance.
D+3	H+1	Squad 01 reports battle damage.
D+3	H+2	Squads 01 and 02 depart area and proceed to rally point with the Platoon Commander, for extraction.
		A sortie of helicopters is ordered for the Platoon extraction.
		Squads 01 and 02 are extracted. Helicopters return to the LHA.
		Mission Complete.

Table 6. Tactical Scenario Timeline

The ESG repositions within littoral waters of Califate to show defensive and humanitarian resolve. The Task Force initiates an active Maritime Interdiction Operation (MIO) within the main shipping lanes.

The next day, the MEU deploys forces in support of a defensive operation at the Califate power plant. Special Boat Units support the Califate Coast Guard in coastal patrols and searches of commercial and fishing vessels for smugglers and terrorist remnants.

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APPENDIX B. NSS MEASURES OF EFFECTIVENESS

The MoEs and their descriptions listed here are not inclusive of all predefined MoEs included in the NSS database. This list includes the IP and broadcast network MoEs that are available to evaluate a simulated communication network.

Messages received records the number of messages received in a user definable time interval. Message types that generate this MoE are triggered by start, failed, update, success, cancel events and include, Hard Kill, ID and Track and Trail commands as well as contact and track reports.

Messages sent records the number of messages sent in a user definable time interval. Message types are the same for messages received MoE.

Contact report receipt delay records the average time from a contact report generation to receipt by the destination asset. Times are averaged over all occurrences within each metric reporting interval.

Message receipt delay records the average time from message generation to message receipt at a final destination. Times are averaged over all occurrences within each measure user defined reporting interval. Message types are the same for messages received MoE.

Duplicate messages received records the number of duplicate messages received in a user defined time interval. Duplicate messages are only possible in medium resolution communications or with unassured communications in low resolution. Message types are the same for messages received MoE.

Terminal relay messages received records the number of times messages are received at a terminal relay. A terminal relay is a recipient that both processes and relays the message in question. This MoE is used primarily with non-source routed vice source routed messages. The communication model design for this study only uses source routed messages.

Non-Terminal relay messages received records the number of times the messages are received at non-terminal relay nodes. A non-terminal relay is a recipient that relays, but does not process, the messages in question. This measure applies only to medium resolution communications. Message types are the same for messages received MOE.

Contact reports received records the cumulative total number of contact reports, of user defined types, generated and received at the time in question. When multiple receiving assets are specified, the contact reports generated by each detected assets will be counted once for each contact report receipt at the each of the designated receiving assets.

Explicit communication load records the level of priority traffic, such as contact and track reports, commander tasks and task status, at user specified terminal in kilobytes per hour. This measure is applicable only when medium resolution communications are specified for the scenario and IP networks are used in the routed communication plan.

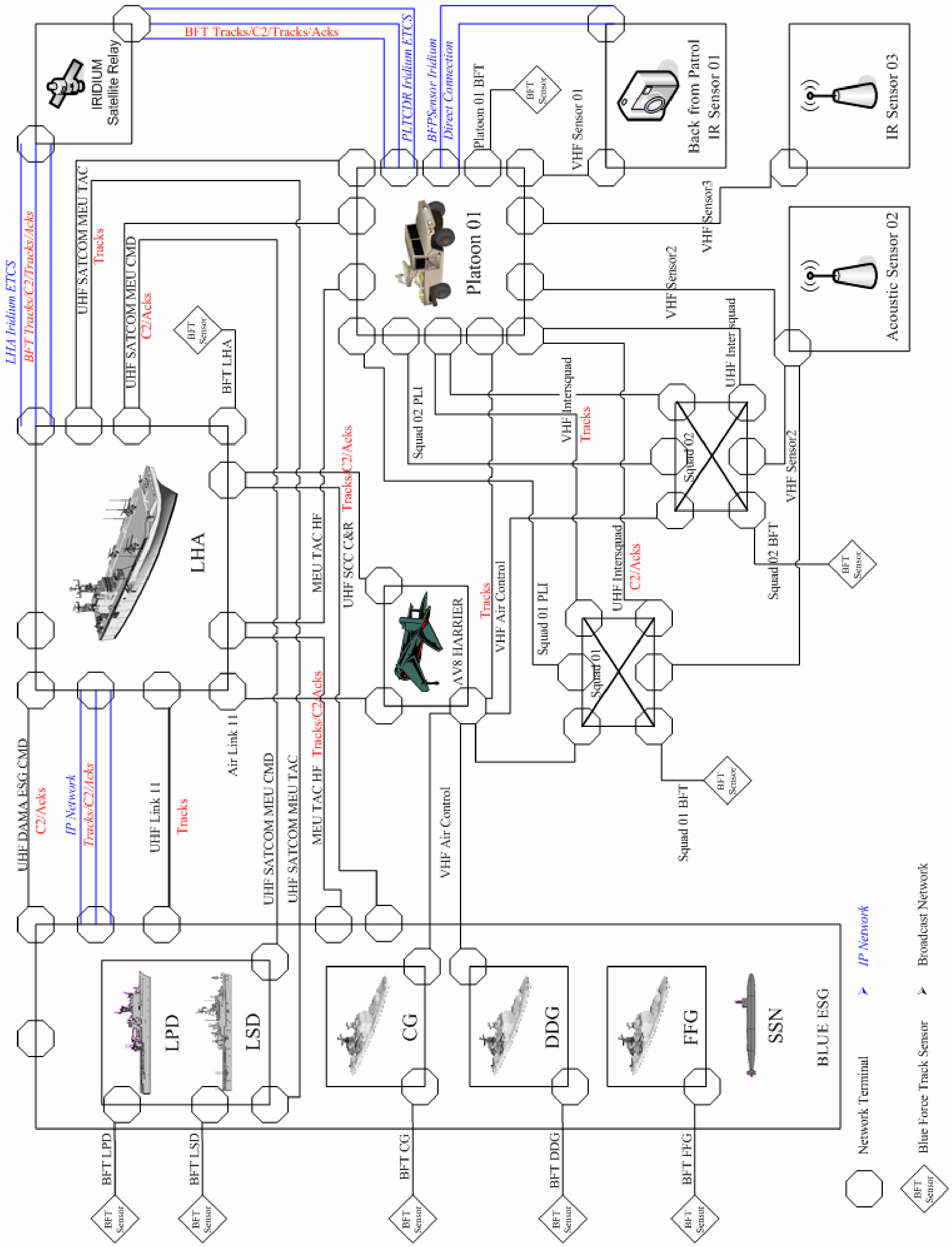
Background communication load records the level of background traffic at selected locations in kilobytes per hour. This measure is also applicable only when medium resolution communications are specified for the scenario and IP networks are used in the routed communication plan.

Communication message loading records the number of messages passing through user specified link terminals. This measure is also applicable only when medium resolution communications are specified for the scenario and IP networks are used in the routed communication plan.

Contact report count records the total number of contact and track reports received at specified fusion centers during a user defined time period. This measure can be used in conjunction with received contact reports and contact report delay to determine precision and timeliness of asset reporting efficiency.

Communication send volume records the communication traffic volume in kilobytes, of user specified content sent between selected assets and via specific link terminals. This measure is also applicable only when medium resolution communications are specified for the scenario and IP networks are used in the routed communication plan.

APPENDIX C. NSS ROUTED COMMUNICATIONS DESIGN



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